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ORIGINAL ARTICLE

Assessment of particulate matter and lead levels in the Greater Cairo area for the period 1998–2007

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KEYWORDS

Particulate matter (PM);
Lead (Pb);
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Air quality limits (AQL)

Abstract A health risk assessment study conducted in 1994 for the Greater Cairo (GC) area evaluated the environmental health risks to Cairo residents and determined the major health hazards of ambient lead and particulate matter. In order to determine the spatial and temporal trends in the concentration of these substances, the Egyptian environmental affairs agency (EEAA) decided to initiate a pollutant monitoring program. This was conducted with the help of the USA and Denmark. Numerous monitoring sites were established in Egypt. These sites monitored ambient particulate matter (PM_{10} and $PM_{2.5}$) and lead through the Cairo air improvement project (CAIP) funded by USAID. In addition, measurements of SO_2, NO_2, CO, and O_3 were performed through the Egyptian information and monitoring program (EIMP) funded by DANIDA. This paper describes the ambient particulate matter and lead levels over a period from 1998 through 2007 for the all monitoring sites in GC. In addition, discussions of the sources of the observed pollutants are presented.

Introduction

Megacity is a general term for cities together with their suburbs or recognized metropolitan area, usually with a total population in excess of 10 million people. There is no exact definition of its boundaries. In 2000, 22 cities were identified as megacities: they are Tokyo, Osaka-Kobe, Mexico City, New York, Los Angeles, São Paulo, Mumbai, Delhi, Kolkata, Buenos Aires, Shanghai, Jakarta, Dhaka, Rio de Janeiro, Karachi, Beijing, Cairo, Moscow, Manila and Lagos.

Air pollution in urban areas comes from a wide variety of sources. The single most important source for the classical pollutants sulfur dioxide (SO_2), nitrogen oxide (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs) and particulate matter (PM) is generally fossil fuels. Of particular importance is the burning of fuels for road transport and electricity generation. There are three major sources of air pollution in urban areas, namely mobile sources, stationary sources, and open burning sources and these can be categorized into source groups: motor traffic, industry, power plants, trade and domestic fuel.

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Gurjar et al. (2007) [1] evaluated emissions and air quality pertaining to all megacities. They also ranked megacities in terms of their trace gas and particle emissions and ambient air quality, based on the newly proposed multi-pollutant index (MPI) which considers the combined level of the three criterion pollutants (TSP, SO_2 and NO_2) in view of the World Health Organization (WHO) guidelines for air quality [2]. Based on present MPI values, they found that Dhaka, Beijing, Cairo and Karachi appear to be the most polluted, while Osaka-Kobe, Tokyo, São Paulo, Los Angeles, New York and Buenos Aires are the least polluted megacities.

Cairo, the capital of Egypt, is the largest city in Africa and the Middle East. It is located on the banks and islands of the Nile in the north of Egypt. The population of the Cairo urban

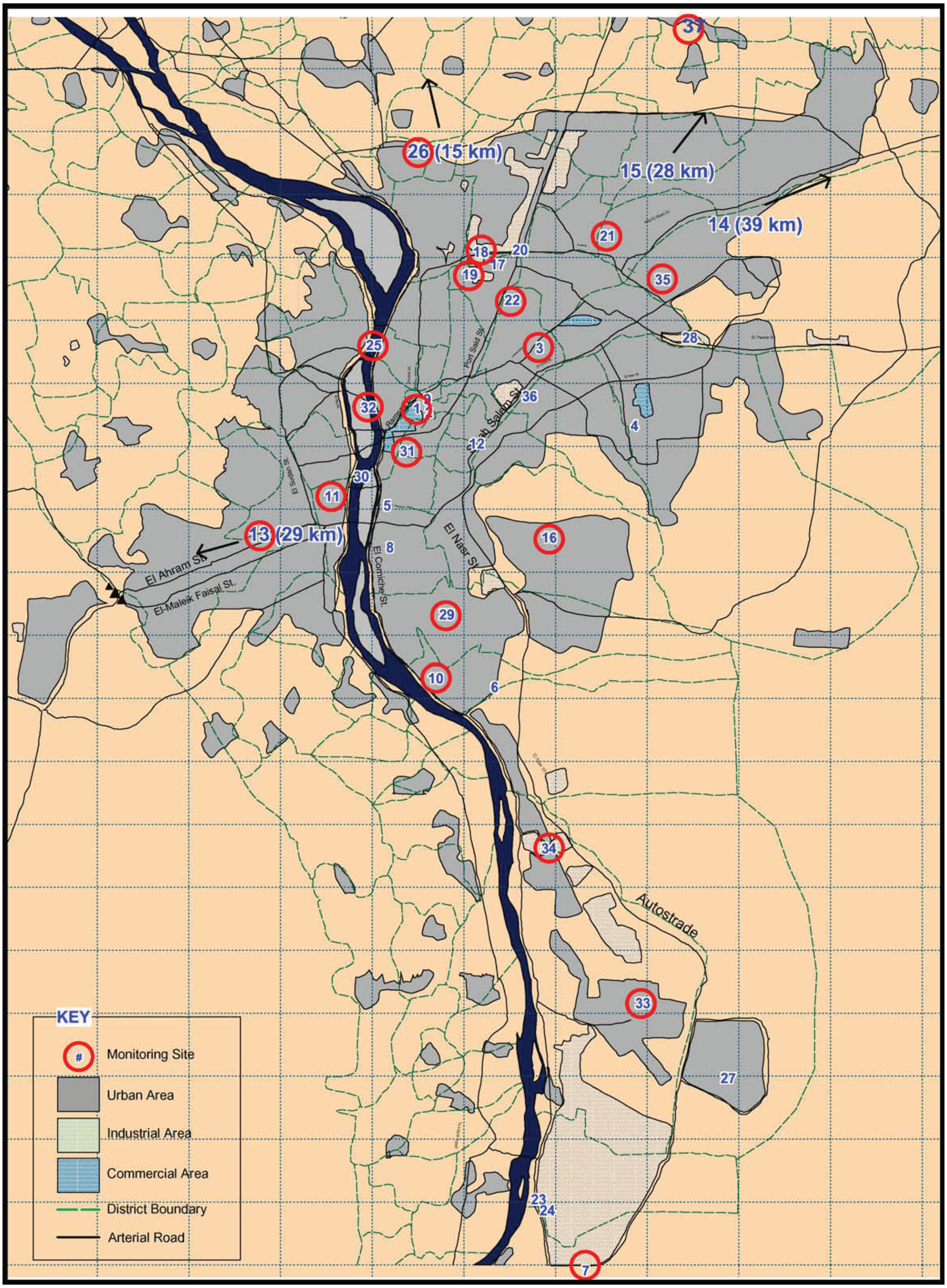

Figure 1 CAIP monitoring site locations in the GC area.

agglomeration is 10.8 million and is projected to reach 13.1 million by 2015. GC consists of Cario, Giza and Kalubia, and has a population of more than 20 million (for the three governorates including the urban area).

Cairo has a hot, dry desert climate. The monthly average temperature ranges from 14 °C in January to 29 °C in July. The maximum daily temperature can reach 43 °C in the summer. The average annual rainfall is only 22 mm and the monthly maximum of 7 mm occurs in December.

Although Cairo itself is only about 1000 years old, parts of the metropolis date back to the time of the Pharaohs. In the nineteenth century, one of the city's rulers, Khedive Ismail (1863–1879), sought to transform Cairo into a European-style city. This, along with the British occupation of Cairo in 1891, led to the development of new suburbs for affluent Egyptians and foreigners. By the turn of the century, most commercial activity was also moving into modern Cairo.

The urbanization of the GC area has been facilitated by an extensive flood control program and improved transport facilities developed over the past 30 years. Cairo is the only city in Africa with a metro system. Although the conservation of agricultural land has long been a priority of Egyptian development policy, much of the critically needed arable land in Cairo is being lost to urban development, half of which is illegal; the

Figure 2 EIMP monitoring site locations in the GC area.

remainder is planned developments in the desert. Cairo has about one-third of Egypt's population and 60% of its industry. It is one of the world's most densely populated cities, with one of the lowest provisions of road space per capita; it is experiencing a dramatic growth in the number of private vehicles. The government has exacerbated this situation by spending on bridges and overpasses and by heavily subsidizing fuel, all of which promote the use of private vehicles.

Emissions from industry and motor vehicles cause high ambient concentrations of PM, SO_2, O_3, NO_x and CO in Cairo. However, continuous measurements of these pollutants need to be conducted to establish the extent of the air quality problem [3]. Lead levels in Cairo are among the highest in the world: for example, the annual average concentration of lead in the Shoubra Kheima area (an industrialized environment containing several lead smelters) is 23.09 on 1999 μg/m³ and is estimated to cause 15–20,000 deaths a year, according to a 1996 report by the Egyptian environmental affairs agency. PM lead concentrations ranged from 0.5 μg/m³ in a residential area to 3 μg/m³ at the city center [4].

Methodology

During the past ten years, two programs have been initiated to routinely collect air quality monitoring data on a continuing basis; prior to these programs the concentration of the main atmospheric pollutants was only measured by research institutions for research work.

Air quality monitoring programs

The environmental information and monitoring program (EIMP) has established a national monitoring network consisting of 42 air quality monitoring stations; this network was

Table 1 CAIP air quality monitoring sites.

CAIP site #	CAIP site name	Site code	Samplers		Site type
			PM2.5	PM10	
1*	Quallaly Square	EQS	X	X	Traffic
2	Gemhoroya Street	GEM			Traffic
3*	El Waily	MET	X	X	Mixed
4*	Nasr City	NRC			Residential
5*	Fum Al-Khalig	FAK		X	Traffic
6	Maadi/Digla	CAC	X	X	Residential
7*	Tebbin South	TBS	X	X	Industrial
8	Old Cairo	UHC	X	X	Residential
9	Ramses Square	ERA		X	Traffic
10**	Old Maadi	CAI	X	X	Residential
11	Giza	CEH	X	X	Residential
12	El Darb El Ahmer	AAU		X	Mixed
13*	6th October City	OCT	X	X	Residential
14*	10th Ramadan City	RAM	X	X	Residential
15	Bilbeis	BLB			Background
16	Mokatam	ATI		X	Residential
17	Shoubra el-Kheima	LSA	X	X	Source
18	Shoubra el-Kheima	APC	X	X	Industrial
19	El Sahel	TTI	XC	XC	Industrial
20	Shoubra el-Kheima	MIC	X	X	Industrial
21	Matarya	DRC	X	X	Mixed
22	El Waily	AMP		X	Mixed
23	Tebbin	TES	X	X	Industrial
24	Tebbin	LSB	XC	XC	Source
25	Imbaba	HTI		X	Residential
26	Kaha	KFC	X	X	Background
27	15th May City	MAY		X	Residential
28	Almaza	HDM		X	Residential
29	Basateen	LRC		X	Mixed
30	Giza	CYC		X	Residential
31	Tahrir Square	AUC	X	X	Mixed
32	Zamalek	BIS	X	X	Residential
33	Helwan	HFS	X	X	Residential
34	El Massara	SBH	X	X	Mixed
35	Heliopolis	OLS	X	X	Residential
36	Abbasia	EGS	X	X	Industrial
37	Abu Zaabal	ABZ	X	X	Industrial

X – one $PM_{2.5}$ and/or PM_{10} sampler at site.
XC – two $PM_{2.5}$ and PM_{10} samplers collocated at site.
Site # 2 was cancelled on March 18, 2002. Site 4 was cancelled on January 1, 2001. Site 15 was moved to site 37 on February 15, 2002.
Remark: UTM Coordinates for GC area is in UTM zone number 36.
* Located at or near EIMP monitoring site.
** Monitoring site with collocation of AirMetrics and BGI samplers.

funded by DANIDA. Fourteen of the EIMP sites are located in the GC area. The Cairo air improvement project (CAIP) has established a network of 34 stations in the GC area to monitor ambient air levels of particulate matter and lead and two monitoring sites as source stations in lead smelter locations in Shoubra Kheima and Tebbin. The CAIP monitoring effort was intended to provide data to assess the efficacy of CAIP and other initiatives to improve air quality in Cairo. These initiatives included: implementation of a vehicle emission testing and tune-up program; introduction of CNG-fueled buses for public transportation; and abatement of lead by secondary lead smelter design improvements and lead smelter relocation [5,6].

Formal operation of the CAIP air monitoring network began on 1 October 1998 and one full year of monitoring data was collected as of 30 September 1999. The period of 1 October 1998 through 30 September 1999 is considered a ''baseline year''. The baseline year monitoring data will serve as a ''benchmark'' against which future monitoring data can be compared to assess air quality trends. CAIP and EIMP are presented in Figs. 1 and 2 for the two networks in the GC area. CAIP concentrates on pollution from particulate matter (PM) and lead (Pb) which were the major harmful criterion pollutants in the GC area according to the health risk assessment study [4] conducted by the Egyptian government and USAID in 2004, while EIMP concentrates on measuring the other criterion pollutants, SO_2, NO_2, O_3 and CO.

Meteorological data are also being recorded by both programs as the most important parameter for explaining the air quality data. An automatic weather station (AWS) is recording: wind speeds, wind direction, air temperature, solar radiation and relative humidity.

Table 1 presents the CAIP monitoring sites locations and the monitoring equipment in each site while Table 2 presents the list of EIMP monitoring sites in the GC area. This table includes the monitoring and sampling equipment at these sites [7].

Objectives of air quality monitoring

The overall objective of the air quality measurement program is to obtain a better understanding of urban and residential air pollution [2,3] as a prerequisite for finding effective solutions to air quality problems and for sustainable development in the urban environment.

It will be important to identify areas where the air quality limit (AQL) values are exceeded and to identify possible actions to reduce the pollution load and to improve the general environmental conditions of the country.

The main purpose of the air quality measurements is to identify the possible exposure of the population to pollutants. Information will be collected on ambient air pollution levels in areas where people live and work. The measurements will cover areas of impact from various sources of pollution.

To enable assessment of air quality and trend analyses, a network of fixed stations is needed. There are international rules for estimating the minimum number of sampling points for fixed measurements in order to assess compliance with limit values for the protection of human health.

CAIP monitoring sites equipment

AIRmetrics™ samplers are used to collect $PM_{2.5}$ and PM_{10} samples. At 26 sites, both sizes of PM ($PM_{2.5}$ and PM_{10}) and Pb ($Pb_{2.5}$ and Pb_{10}) are measured. At 10 of the monitoring sites, only PM_{10} and Pb_{10} measurements are performed. Two each of the $PM_{2.5}$ and PM_{10} samplers are placed at two sites (site nos. 19 and 24). Data collected by these collocated samplers are used to estimate the precision of the PM and Pb measurements [6]. The model number of the AIRmetrics™ samplers is MiniVol 4.2, and that of the quartz filters is 4.4 cm (Filter Grade: QMA, Whatman Cat No: 1851047).

Samples are collected concurrently at all monitoring sites on a six-day schedule. During each sampling event, the samplers are programmed to continuously collect a particulate matter sample over a 24-h period (0000–2400 h). The collocated sites in the CAIP network are numbers 19 (El Sahel) and 24 (Tebbin).

One PM_{10} BGI air sampler (EPA-certified) was installed at CAIP site number 10 with collocation with AIRmetrics™ for quality control purposes. The correlation coefficient of readings for both AIRmetrics™ and BGI are $R^2 = 0.9287$ for the baseline year, 0.9351 for year 2000 and 0.9322 for year 2001.

Table 2 EIMP monitoring sites in the GC area [5].

No.	ID	Area type	PM_{10}		Starting date
			Monitors	Samplers	
1	Quallaly	Urban Center	1		24-May-98
2	Gomhoryia	Street Canyon		1	25-December-97
3	Abbassyia	Urban/Residential	1		22-May-99
4	Nasr City	Residential		1	08-October-98
5	El-Maadi	Residential		1	10-December-98
6	Tabbin	Industrial	1		27-October-97
7	Tabbin South	Industrial			19-October-98
8	Fum El-Khalig	Road side/Urban	1		07-November-98
9	Abu Zabel	Industrial/Residential		1	16-November-98
10	Shoubra El Kheima	Industrial		1	01-May-98
11	Cairo University	Residential			18-July-98
12	Kaha	Back	1		1-July-2001
13	6 October	Residential/Industrial		1	12-January-99
14	10 Ramadan	Residential		1	15-December-98

EIMP monitoring sites equipment

The instruments used in the EIMP air quality monitoring network can be classified as automatic monitors, semiautomatic samplers and samplers [8]. There are samplers and monitors for PM_{10}, and monitors for criterion pollutants other than PM and lead.

Table 3 presents the monitors being used in the EIMP air quality monitoring network and Table 4 shows the average flow rates for the different type of samplers in a specified time.

PM_{10} HiVol sampler

TEI model 600 PM10 (thermo environment).
Flow rate 68 m^3/h.
US EPA approved.

PM_{10} AIRmetrics sampler

The MiniVol Portable AIRmetrics™ sampler is an ambient air sampler for particulate matter and non-reactive gases. The EIMP program is using it to sample 24-h average PM10 every six days through a seven-day programmable timer. The flow rate is about 5 L/min.

Table 3 Monitors used in the EIMP air quality monitoring network.

Pollutants	PM_{10}
Concentration units	(μg/m^3)
Measurement technique	Tapered filter element oscillating microbalance
Instrument type	Beta gauge ambiant particulate monitor

Table 4 Summary of flow rates.

Instrument	Flow rates			
	m^3/min	m^3/h	m^3/day	m^3/week
Thermo HiVol TSP/PM_{10}	1.13	67.8	1627.2	11390.4
Thermo PM_{10} monitor	0.0189	1.134	27.216	190.512
AIRmetrics™	0.005	0.3	7.2	50.4

Table 5 Ambient air quality limits (AQL), μg/m^3.

Pollutant	Law 4 after modification by the executive regulations of October 2005	Averaging time
Total suspended	230	24 h
particulate (TSP)	90	Annual
PM_{10}	150	24 h
	70	Annual
Lead in PM_{10}	0.5	24 h in Urban areas
	1.5	Six month average in industrial areas

TSP HiVol sampler

TEI model 610 TSP HiVol (thermo environment).
Flow rate 68 m^3/h.
Glass fiber filter.
Concentration of selected elements (Pb, Zn, Cd, etc.) may be sampled.
US EPA approved.

Air quality limit values

The assessment of air quality is presently being linked to air pollution levels and to population distribution. To safeguard health, concentrations of selected harmful air pollutants should be limited and related to given ambient air quality standards.

Air quality limit values for particulate matter and lead are given in the executive regulations of the environmental law no. 4 of Egypt (1994). These air quality limit values are presented in Table 5.

Results and discussion

Monitoring data summary

Ambient particulate matter data in the GC area

Generally high levels of $PM_{2.5}$ and PM_{10} were recorded across the entire GC area. This is due to the arid climate and very low rainfall resulting from the area being surrounded by deserts.

Fig. 3 shows the monthly average PM_{10} concentrations for October 1998–December 2007 at the Kaha monitoring site which is the background site of CAIP, while Fig. 4 shows the monthly average of $PM_{2.5}$ concentrations for the same site for the same period. $PM_{2.5}$ is measured in GC only through the CAIP network [8]. The Kaha site is located in the north of the GC area and is upwind of the general area because the wind blows mostly from the north.

The high concentrations of PM are, again, due to the arid climate, as described above.

The average $PM_{2.5}/PM_{10}$ ratio for all paired measurements made during the baseline year and the subsequent three years is 0.51. The variation around the mean ratio expressed as the standard deviation is ± 0.13. In general, $PM_{2.5}/PM_{10}$ ratios obtained for all monitoring sites during sampling events were approximately the same magnitude and exhibited a similar temporal variation. Also, it can be concluded that the 24 h daily average is fluctuating around the average value stated by the law and the new executive regulations of 2005 which is 150 μg/m^3.

Fig. 5 shows the fluctuations of PM_{10} concentrations in the past ten years in GC for some chosen monitoring sites representing different types of area: Abbasya (mixed site), Fum Al-Kalig and Quallaly (traffic sites), Maadi, Helwan and Heliopolis (residential sites), Shoubra Khema andTebbin (industrial sites), Massara (mixed site) and Kaha (background site).

It appears clearly that PM_{10} concentrations are high and more than the annual average stated in the environmental law of Egypt (no. 4/1994) and the executive regulations approved on October 2005 (70 μg/m^3) as the annual average limit. Values are lower in residential areas such as Maadi and

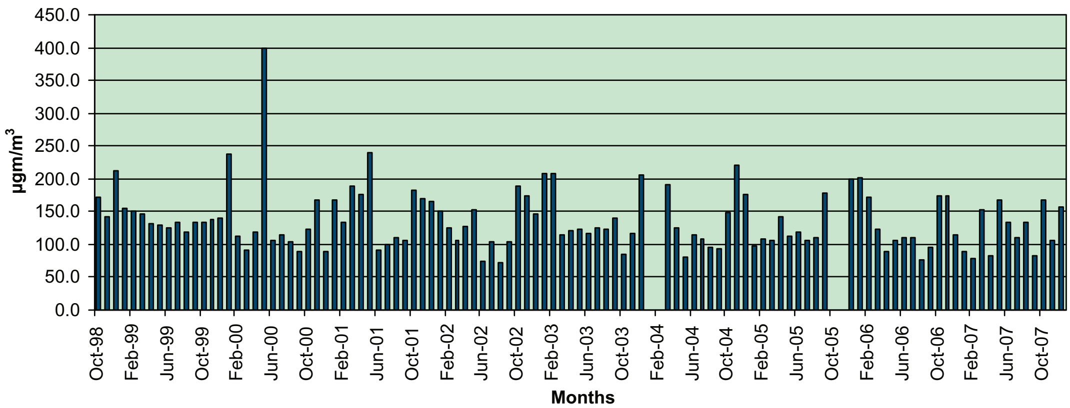

Figure 3 Kaha monthly average of PM_{10} concentrations from October 1998 through December 2007.

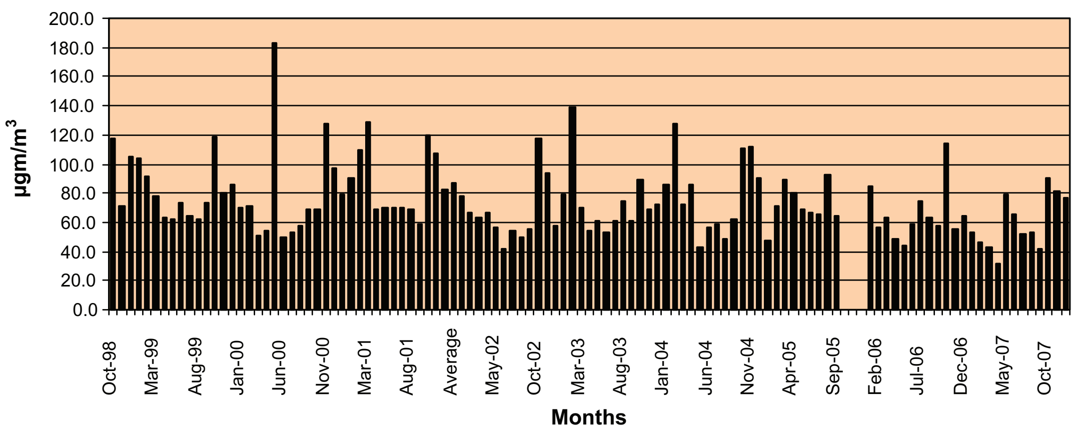

Figure 4 Kaha monthly average $PM_{2.5}$ concentrations from October 1998 through December 2007.

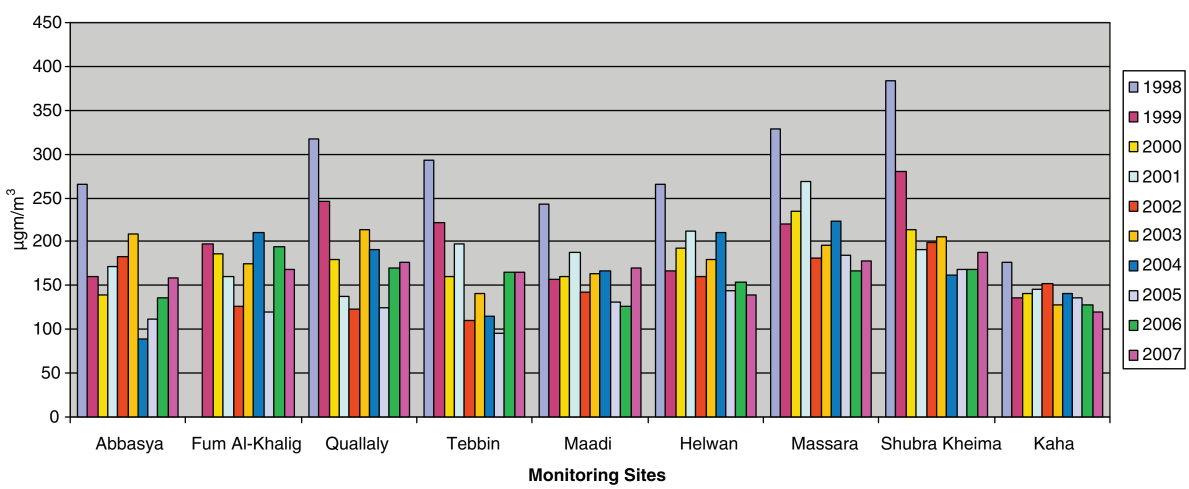

Figure 5 Annual average PM_{10} concentrations from October 1998 through December 2007 in different monitoring sites in the GC area.

Heliopolis than in industrial areas as Shoubra Kheima and traffic areas such as Quallaly. The concentration of PM_{10} in Kaha (background site) is lower than the other monitoring sites because of its location upwind of the GC area.

Another cause for increasing PM_{10} concentrations is the existence of more than 15,000 industrial establishments in the GC area. This was started during the Second World War when the Allied forces built lots of foundries, smelters and small factories for the provision of spare parts. This continued after the 1952 revolution as the population increased and now there are no defined boundaries between the three governorates. At the beginning of 2009 Giza split into two governorates (Giza and 6th of October) and Cairo split into two governorates (Cairo and Helwan).

Sources of PM_{10} were investigated in 1999 and 2002 to identify the major source of pollution in the GC area. Fig. 6 shows the average source contributions of PM_{10} emitted from different source categories [6,9] in the GC area based on the source attribution study (SAS) conducted earlier. The first column presents the source attribution results in the GC area during winter 1999; the second column presents the source attribution results in fall 1999; while the third column presents the source attribution results in summer 2002.

These data show that sand and soil dust contribute between 30% and 45% of the particulate matter and that burning of agricultural waste and garbage is considered to be one of the main causes of higher values of concentrations of particulate matter in the atmosphere.

Comparison of PM_{10} in the GC area and other megacities

PM_{10} average annual data were compared in terms of annual average in some megacities [10], and it was concluded that the GC area had the maximum values and that this is due to the arid climate; there is very little rainfall and an almost constant northern wind which carries dust and sand particles from the deserts surrounding the GC area and from the Nile delta. The comparison of annual averages of PM_{10} and the conclusion are presented in Fig. 7. The concentrations of PM_{10} are higher than in Los Angeles, Mexico City, Santiago and Bogotá.

Ambient lead data

The annual average Pb_{10} and $Pb_{2.5}$ concentration recorded during the period of 1998 through 2007 are shown in Fig. 9 in the GC area (annual averages of all monitoring sites) [4,10]. Fig. 8 shows the monthly average concentrations of Pb_{10} during the same period for the Shoubra Kheima monitoring site which is downwind of four lead smelters. These lead smelters were closed and moved from the area in July 2002. The highest annual average Pb_{10} levels recorded were 26.2 and 25.4 $\mu g/m^3$ at the Shoubra Kheima (site no. 18) and El Sahel (site no. 19) monitoring stations, respectively, during the baseline year (October 98 to September 99). The annual aver-

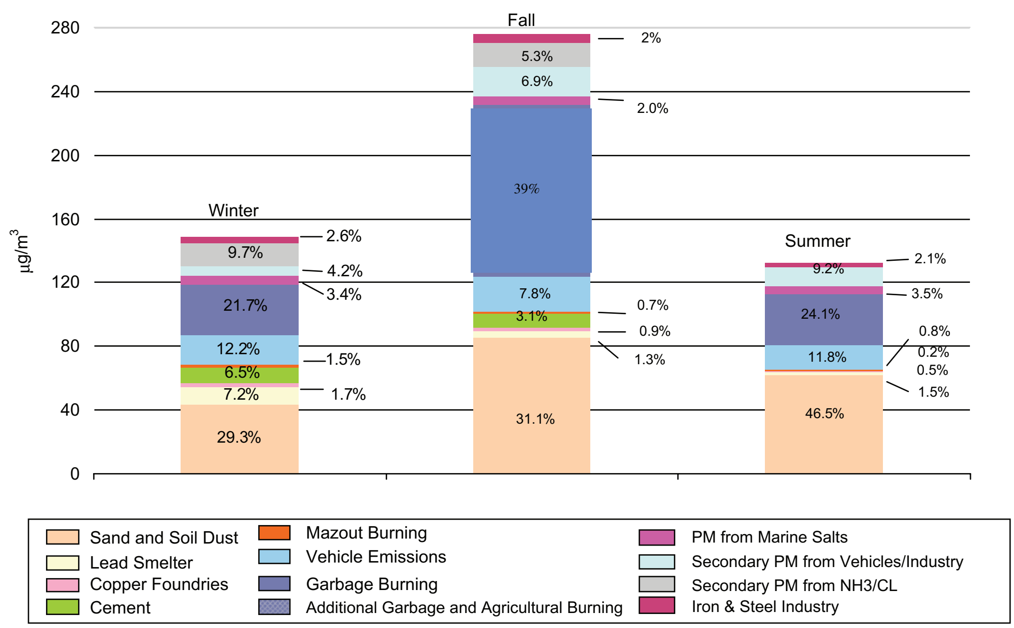

Figure 6 Average percentage contribution of PM_{10} source categories in the GC area.

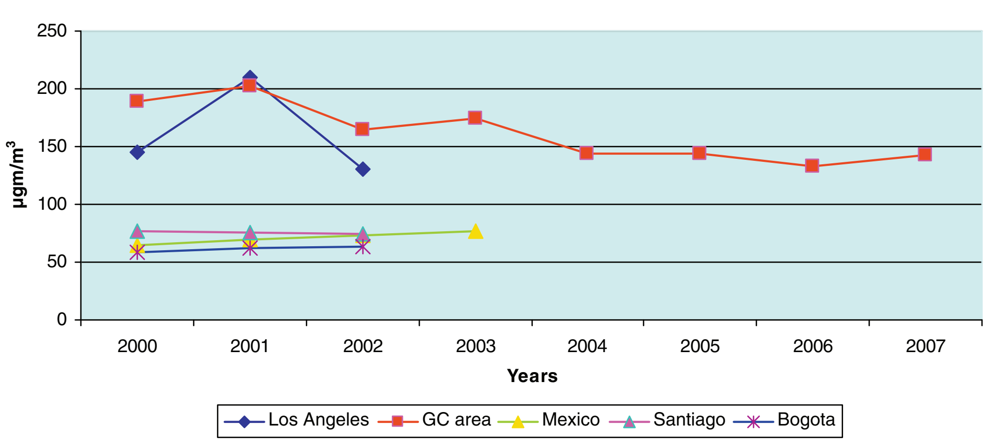

Figure 7 Average annual concentrations of PM_{10} in some megacities.

age Pb_{10} levels decreased each year after the baseline year until July 2002 when the lead smelters in the area were closed and moved to the industrial area of Abou Zaabal.

The monthly average concentration of lead particulate Pb_{10} at the Shoubra El Khema site, which had the highest levels of lead concentrations from 1998 to 2007, is shown in Fig. 9. A large reduction in lead concentration is found after 2002 due to the closure of all operating lead smelters.

Generally, the non-attainment sites are located in the Shoubra Kheima and Tebbin regions where Pb_{10} concentrations are more than the annual limit of 1.5 gm/m^3. The lead concentrations in these areas have decreased dramatically since 2002.

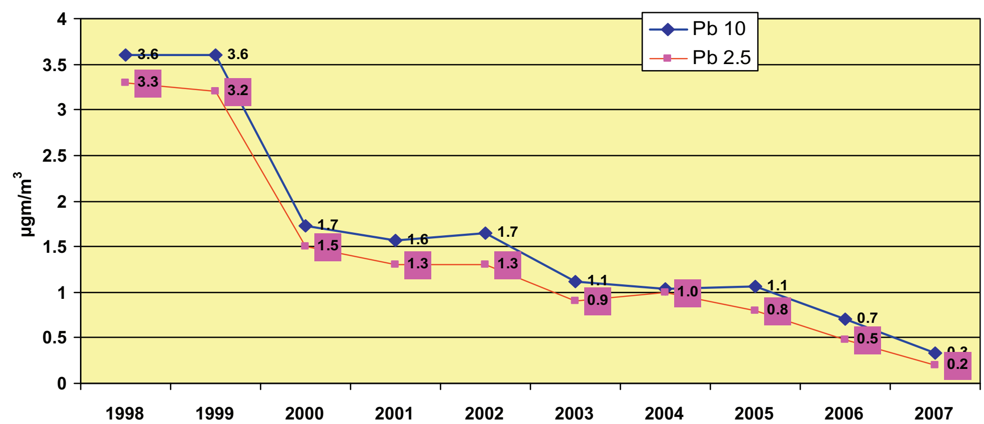

Figure 8 Annual average concentrations of Pb_{10} and $Pb_{2.5}$ from 1998 to 2007 for the GC area (annual averages of all monitoring sites in the area).

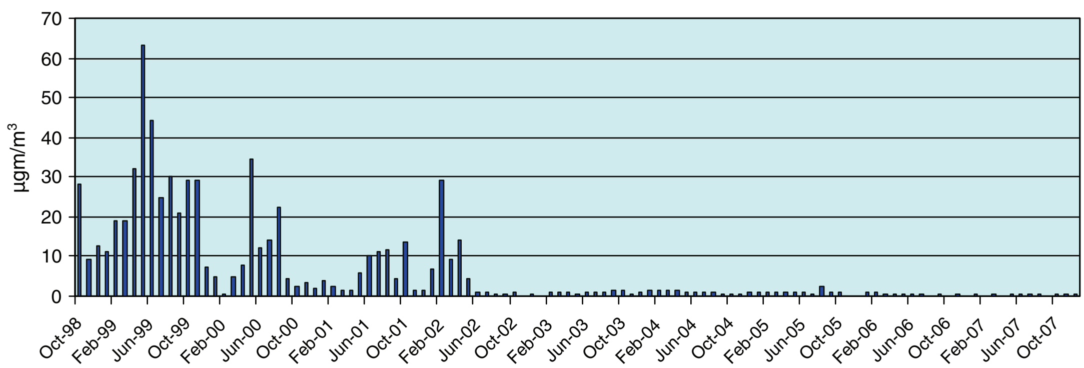

Figure 9 Monthly average Pb_{10} concentrations from 1998 to 2007 for the Shoubra Kheima industrial site.

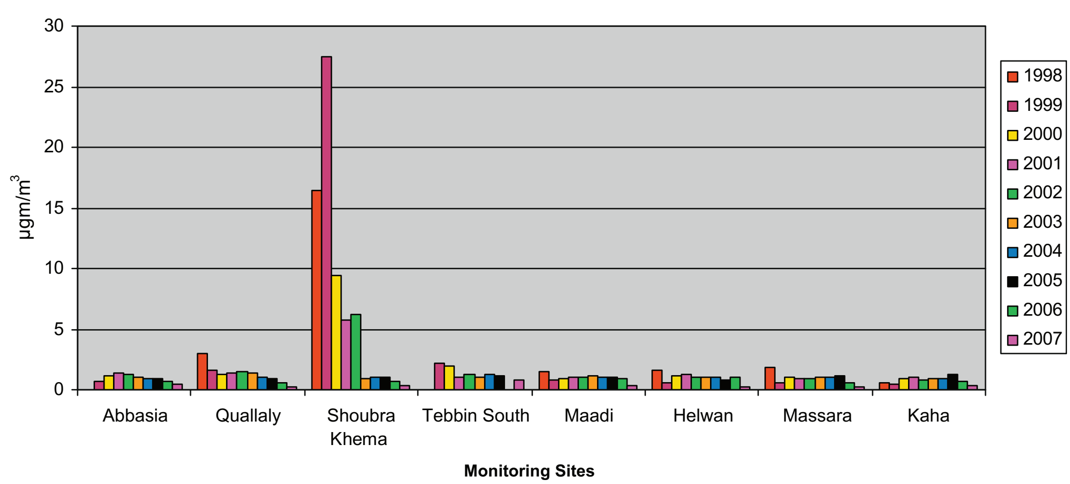

Figure 10 Annual average Pb_{10} concentrations from 1998 to 2007 for some monitoring sites in the GC area.

Figs. 10 and 11 show the annual average concentrations of Pb_{10} and $Pb_{2.5}$ for different monitoring sites in the GC area from 1998 to 2007. Lead concentrations are clearly higher for the industrial areas (Shoubra Khema) and traffic sites (Quallaly) especially from 1998 till 2002 and the concentrations decrease after 2002.

Relations between Pb_{10}/PM_{10} and $Pb_{2.5}/PM_{2.5}$

Table 6 shows the ratios of the annual average concentrations of Pb_{10}/PM_{10} for the period 1999 through 2007 of $Pb_{2.5}/PM_{2.5}$ for the period 1999 through 2003 for different monitoring sites in the GC area. The monitoring sites were chosen to represent

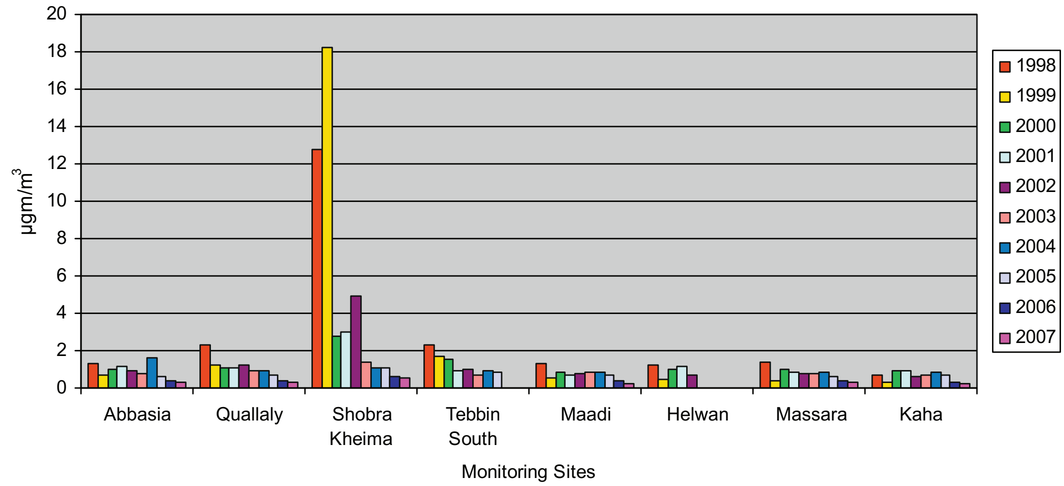

Figure 11 Annual average $Pb_{2.5}$ concentrations from 1998 to 2007 for some monitoring sites in the GC area.

Table 6 Ratios of Pb_{10}/PM_{10} and $Pb_{2.5}/PM_{2.5}$ for eight monitoring sites in the GC area.

Site	Year	Abbasia (site #36)	Quallaly (site # 1)	Shoubra Kheima (site # 10)	Tebbin South (site # 7)	Maadi (site # 10)	Helwan (site # 33)	Massara (site#34)	Kaha (site # 26)
Pb_{10}/PM_{10}	1999	0.68/150	1.64/246	27.44/269	2.18/259.5	0.78/157.7	0.62/166.6	0.56/219.4	0.44/140
	%	0.453	0.667	10.201	0.840	0.495	0.372	0.255	0.314
	2000	1.19/ 139.3	1.26/180.0	9.42/225	1.92/254.3	0.93/159.9	1.19/192.9	1.01/234.9	0.97/146
	%	0.854	0.700	4.187	0.755	0.582	0.617	0.430	0.664
	2001	1.38/172.3	1.44/137.8	5.79/236	1.02/267.9	1.02/187.6	1.32/211.6	0.95/268.1	1.09/153
	%	0.801	1.045	2.453	0.381	0.544	0.624	0.354	0.712
	2002	1.21/183.5	1.46/123.4	6.19/198	1.28/288.3	1.04/142.7	0.98/159.9	0.93/181.8	0.76/123
	%	0.659	1.183	3.126	0.444	0.729	0.613	0.512	0.618
	2003	1.08/209.4	1.36/213.9	0.93/223	1.00/217.7	1.16/162.7	1.00/179.1	1.01/195.3	0.96/158/
	%	0.516	0.636	0.417	0.459	0.713	0.558	0.517	0.608
	2004	0.95/89.7	1.07/190.7	1.05/–	1.22/238.7	1.08/166	0.99/210	1.06/222.9	0.94/–
	%	1.059	0.561	0.000	0.511	0.651	0.471	0.476	0.000
	2005	0.88/111.03	0.88/124.5	1.09/131	1.15/212	1.02/131	0.76/143	1.17/184	1.21/99
	%	0.793	0.707	0.832	0.542	0.779	0.531	0.636	1.222
	2006	0.67/135.6	0.59/169.24	0.70/189	–/167	0.94/125.6	1.01/154.4	0.53/166.7	0.71/211
	%	0.494	0.349	0.370	0.000	0.748	0.654	0.318	0.336
	2007	0.54/148.4	0.535/160.2	0.61/179	–/–	0.76/151	0.96/132	0.53/169	0.2/122
	%	0.336	0.333	0.34	0.000	0.503	0.727	0.314	0.16
Average ratio (%)		0.704	0.731	3.084	0.562	0.655	0.555	0.437	0.639
$Pb_{2.5}/PM_{2.5}$	1999	0.7/82	1.3/104	18.2/269	1.7/112	0.5/70.8	0.5/72.4	0.4/78.2	0.3/79
	%	0.854	1.250	6.766	1.518	0.706	0.691	0.512	0.380
	2000	1.0/81	1.1/116	2.8/225	1.6/113	0.9/78	1.0/84	1.0/91	0.9/79
	%	1.235	0.948	1.244	1.416	1.154	1.190	1.099	1.139
	2001	1.1/84	1.1/106	3.0/236	0.9/108	0.7/74	1.2/81	0.8/96	0.9/87
	%	1.310	1.038	1.271	0.833	0.946	1.481	0.833	1.034
	2002	0.9/71	1.2/90	4.9/198	1.0/102	0.8/63	0.7/62	0.8/61	0.6/62
	%	1.268	1.333	2.475	0.980	1.270	1.129	1.311	0.968
	2003	0.8/87	0.9/86	1.4/223	0.7/94	0.8/99	1/–	0.8/88	0.7/86
	%	0.920	1.047	0.628	0.745	0.808	0.000	0.909	0.814
Average ratio (%)		1.117	1.123	2.477	1.098	0.977	1.123	0.933	0.867

The annual average Pb_{10}/PM_{10} and $Pb_{2.5}/PM_{2.5}$ ratios for the eight chosen monitoring sites are 0.921% and 1.214%, respectively.

the different site types (background, industrial, residential, traffic and mixed). Each year's annual average concentrations are followed by the percentages (%) for the same year.

It can be concluded from Table 6 that the lead concentrations are high in 1999 especially in the industrial sites such as Shoubra Kheima. The value of Pb_{10}/PM_{10} in 1999 was 10.201% which means that 10.2% of the PM_{10} was pure lead in the Shoubra Kheima area. This value decreased gradually till it reached 0.34% in 2007. In comparison, the ratio of Pb_{10}/PM_{10} in 1999 for Quallaly (traffic monitoring site) was 0.667% in 1999 and in 2007 only 0.333%. For the background site (Kaha) the ratio was 0.314% in 1999 and 0.16% in 2007. These values are indicators of the efforts to reduce lead concentrations in the GC area by moving industry to new assigned areas and using new technologies for production.

It can be concluded too that the ratios of $Pb_{2.5}/PM_{2.5}$ in 1999 for industrial sites, traffic sites and the background site fell significantly in 2003, the year when the lead smelters were transferred outside the residential area of GC.

Conclusions

In the GC area there are two air monitoring networks for measuring criterion pollutants. They are the CAIP network funded by USAID and the EIMP network funded by DANIDA. The CAIP network monitors PM and lead, while the EIMP network monitors the other criterion pollutants.

The distribution of PM concentrations is characterized by large-scale spatial and temporal variations, which are probably created, in part, by meteorological conditions. Due to the arid climate, there is a persistent high background PM level in the GC area that will probably always prevent reducing daily PM_{10} levels below the 24-h limit of 70 $\mu g/m^3$. The GC area is considered to be one of the megacities which have the highest concentrations of PM_{10} in the atmosphere.

PM and lead are the major pollutants in the GC area. The average $PM_{2.5}/PM_{10}$ ratio for all paired measurements made during the baseline year and the following three years after is 0.51. Also, the variation about the mean ratio expressed as the standard deviation is ± 0.13. The average $Pb_{2.5}/Pb_{10}$ ratio for all paired measurements during the same period is 0.77 and the variation about the mean ratio expressed as the standard deviation is ± 0.11.

Lead pollution is concentrated in two industrial areas, Shoubra Kheima and Tebbin. The lead concentrations decreased dramatically at these two industrial areas after closing the lead smelter activities in Tebbin and moving the lead smelters from Shoubra Kheima to another industrial area. This decrease in lead concentrations is due to the EEAA initiatives supported by USAID funding.

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